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Cybernetic approach for controlling technology management activities

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Abstract

The growing complexity, relevance and speed of technological developments present significant challenges for technology-oriented organizations and the necessity to focus intensified on their technology management activities to react and deal more effectively with performance issues. Therefore, a well-structured and comprehensible technology management process is crucial for a company´s success in terms of e.g. ensuring a sustainable and efficient allocation of resources with the purpose to persist in the competitive arena. On this account it is essential and important for an organization to be aware of the performance and the cause-effect-relations of technology management activities and to keeping up with technological progress and its influences in order to evaluate and design a company´s technology management efficiently. A further challenge results in the often multifunctional and cross-sectional organization of technology management which demands an integrated consideration within the cybernetic framework for controlling technology management activities. In spite of the recognition of its strategic relevance only fragmented and insufficient concepts as well no accurately definition regarding controlling of technology management activities exists. However it is essential to know the performance of the technology management for designing a result-oriented (effective & efficient) technology management for an organization to be able for acting successful and sustainable. Companies lack of an adequate tool and/or approach to bridge the gap between determine the right strategic aims and their realization as well as simultaneous control of technology management activities. This deficit prevents the development of a cybernetic framework including e.g. measuring instruments or maybe a set of different controlling tools to assess, monitor and to affect activities within the technology management. This paper illustrates an academic research development in progress and pursues to investigate the challenging interplays in research and praxis with regard to control technology management activities. It exemplifies an approach to link technology management activities with a controlling system on basis of cybernetic elements. The long-term aim is to develop an adequate framework for controlling mainly intangible and interactive components of technology management activities.

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Keywords: controlling of technology management activities; performance measurement; technology management effectiveness; cybernetic

1. Tension field – Technology Management

Over the last 25 years, technology management (TM) has received increasing attention from industry and academics due to the growing importance of technologies and the growing complexity of technological developments [1]. This paper focuses especially on the question how to control TM activities, which is important for organizations to allocate their resources efficiently and sustainable to persist in the competition. Nowadays production and product technologies become increasingly relevant for a company´s success and presence in global competition. One of the most crucial driver and influencing factor of this appearance is the certain recognition of the technology´s relevance regarding as a critical capability for companies. Therefore technologies and particularly the management of technological activities are the main characteristically success factors for businesses and a main competitive advantage. Thus, technologies are considered to be one of the most important resources and need to be managed. A comprehensive management of technologies and the associated management of technology activities demand a systematic, structured and transparent management-

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approach and subsequently an instrument to control the mentioned technology management activities for sustainable and resource efficiency issues. For this reason it is highly relevant for an organization to know the performance of technology management activities and to keeping up with technological progress and its business related influence in order to assess and design a firm´s technology management efficiently. For designing result-oriented (efficient and effective) TM it is necessary to know the performance of the TM. Technology management is often cross-sectional and multifunctional organized and involves company´s *»core business process including strategy, innovation, new product development and operations management«* [2]. Furthermore, technology management activities are often organized and realized in an implicit manner without clear process definitions or responsibilities as well the absent evidence of the comprehensible linkage between TM activities and a company´s success [2], [3], [5]. The main reasons for this circumstance are:

- There exists a lack of common understanding and language of technology management in science and industrial applications [3].
- Merely heterogeneous understandings, no accurately definition regarding controlling of technology management activities and only fragmented and insufficient concepts exist.
- Technology management is often cross-sectional and multifunctional organized with a long-term orientation [4].
- Lack of comprehensive approaches in order to quantify TM activities [5].
- So far expenses and benefits of technology management activities cannot be detected assigned and evaluated [4].
- Companies lack of adequate tools and/or methods to bridge the gap between defining the right strategic objective and their realization as well as simultaneous control of technology management activities to achieve rising performance [4].

Derived from mentioned circumstances, following questions are in discussion within this research area and especially for this academic research paper:

- Which (set of) TM activities are meaningful for organizations and which degree of intensity by conducting the selected TM activities is needed? For example an organization within a very dynamically sector needs another set of TM activities in comparison with an organization within an industry of very slow technological developments and changes.
- Which aspects are relevant to TM, e.g. such as business environment and/or organizational structures?

The lack of a systematic approach to manage technologies hinders many organizations in their drive for improved effectiveness in their technology management process [6]. The successful establishment and maintenance of competitive positions based increasingly on the potential of available technologies and the targeted use of these technologies. The complexity and dynamics of the business environment pose special challenges for an effective and efficient technology management. The need to ensure a timely assessment of the activities within the technology management presents companies with the following problems, which were identified and verified within the framework of interviews (here: expertly presented) to derive the need for further research action.

Table 1. Overview of interview participants (exemplary)

Company size (employee)	Revenue	Location	Industry	Interviewed expert
170,000 ww	42 bn USD ww	1300 ww	Facility and automotive	Specialist New Technologies. Technology & Advanced Development Group
275,000 ww	118 bn € ww	n/a	Automotive	Manufacturing Engineering, TM
25,000 ww	3 bn € ww	47 ww	White goods and medical	Director of Construction and Development
17,000 ww	1680 m € ww	40 ww	Food and beverage packaging	Senior Manager TI

ww: worldwide
m: million
bn: billion
TM: Technology Management
TI: Technology Intelligence

Following problems and challenges were mentioned directly from practice:

- Technology-focused investments are usually very expensive and require efficient management.
- Resources for activities to develop, plan and control are limited.
- Increasing technology complexity and shorter technology life cycles.
- No traceability and allocation of value adding activities in the company, as the data are collected (often in form of key performance indicators) either qualitatively or not at all.
- The input of technology management activities (expenditures) can hardly be connected to potential outputs (gains).
- Up to now, no known methods are disposable on the one hand to retrace cause-effect-relationships and on the other hand to assess and link generated input-factors as well output-factors of activities within the technology management process.
- Projects within the technology management process often have unique character; therefore it is difficult to derive patterns and to control quantitative and qualitative factors.

- Lack of systematics to derive and prioritize the specific information needs.
  [Author´s own compilation based on data of interviews]

2. Linking Technology Management with the Controlling-System

2.1. Technology Management Process

Basing in traditional Engineering Management, technology management includes dynamic aspects by facing new opportunities and ongoing challenges such as e.g. globalization, explosion of knowledge, new trends and technologies as well innovations. Technology management consists of a lot of activities in different functional units.
The scope of TM has broadened and has particularly integrated aspects from innovation management (IM) and research and development management (RDM) [7], [8], [9], [10], [11], [12]. The mentioned references are just a selection of definitions to illustrate the scope and the complexity of the various understanding of technology management. The National Research Council (NRC) describes technology management as »*a process, which includes planning, directing, control, and coordination of the development and implementation of technological capabilities to shape and accomplish the strategic and operational objectives of an organization*« [7]. This definition characterizes two dimensions of TM, on the one hand hard aspects, such as science and engineering and on the other hand soft aspects. Furthermore GREGORY describes TM as »*the effective identification, selection, acquisition, development, exploitation and protection of technologies needed to maintain a stream of products and services to the market*« [13]. This paper utilizes a more holistic definition of technology management and refers to the framework of SCHUH [14], see fig. 1.

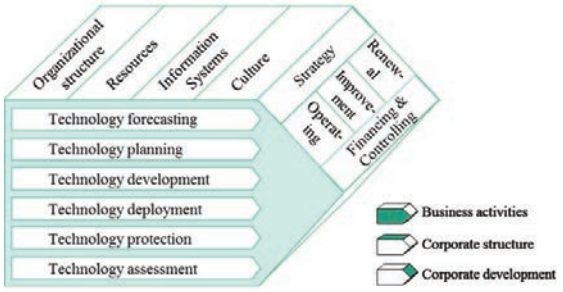

Fig. 1. Technology management framework [14].

In this illustration, technology management includes business activities, corporate structure and corporate development. Business activities comprise technology forecasting, technology planning, technology development, technology usage, technology protection, and technology assessment. The corporate structure illustrates firm´s constitutive elements and the third part of the framework is the corporate development [14].

This technology management framework with the focus on technology forecasting (TF), technology planning (FP), technology development (TD) and technology usage (TU) in the area of »Business activities« constitutes the framework of this proposed approach of controlling technology management activities. TF indicates the identification of current and future technologies. The term TP contains the knowledge as well the selection of the relevant technologies and within TD the relevant technologies will be developed. Afterwards within TU the technology is utilized to create value [14].

2.2. Controlling-System

Controlling is a broad term without a specific taxonomy, because it is need to be seen and operated in the corporate context dependency. Different controlling-concepts differ in objectives, tasks, tools and the underlying organizational structure of the enterprise – depend on the industrial sector, company size, industry dynamics, etc. A controlling-system has the objective to plan systematically, to organize, to manage and to control the business processes and it is always a combination of coordination of planning systems, control systems and information systems [15] [16], see fig. 2.

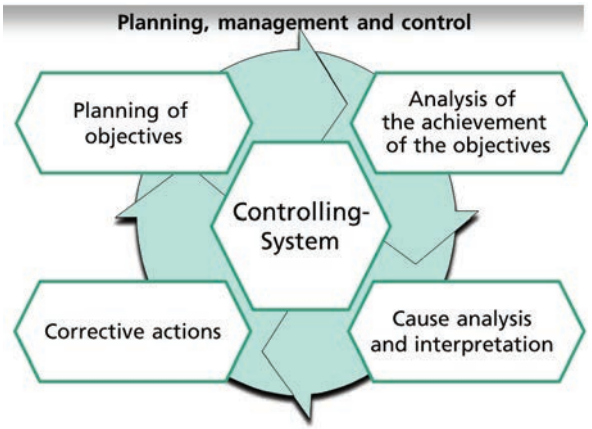

Fig. 2. Components of a controlling-system [15].

In detail within a cohesive controlling-system a systematic definition and allocation of the objectives who need to be pursued will be defined (*planning phase*). Thereupon the target achievement will be measured and analyzed (*analyzed phase*) in terms of a target/actual comparison. Following a cause analysis and interpretation of the detected deficiency will be conducted (*cause analysis and interpretation phase*). Afterwards measures will be developed to eliminate the deviations (*corrective action phase*) and to generate a more transparent information base to plan the subsequent objectives more efficiently [17 - 19].
Once defined objectives are never rigid, they can shift by changing conditions, e.g. economic parameters and organizational conditions. Deviations from targets are part of

everyday business, but they are always associated with efforts, which should be kept as low as possible as a requirement by focusing the resource-based-view within the company. The main point is to draw concrete conclusions from the appeared deviations and to deduce promising measures to optimize the internal planning actions. Controlling is an ongoing analysis of the previous business development and the derivation of short, medium and long-term goals [20 - 22].

2.3. Linking selected technology management activities with the controlling-system

»*What gets measured gets managed*«.
To follow the quote from Peter Drucker, it is necessary to select the correct activities for measuring to be able to manage the entire process, in this context the technology management process. Matching the theoretical understanding of a controlling-system with the technology management framework of SCHUH (see fig. 3) following questions have been arisen:

- Are the right aims have been set?
- Which technology management activities are meaningful and result-oriented for the organization?
- Have been the individual activities efficiently/ inefficiently and effectively?

In the following the mentioned questions are shown graphically in process form (see fig. 3). In the first step aims (e.g. targeted number of new products/technological patents, certain amount of radical/disruptive innovations) are defined. To reach these aims several input factors/ resources are given, e.g. capital, staff, and time. After the sequence of processes (TF, TP, TD, TU) an output is generated. Ideally the output corresponds with the given aims. The efficiency can be defined as output divided by input and one main objective of controlling systems is to improve and maximize efficiency by planning, analyzing and initiating measures (modelled after fig. 2).

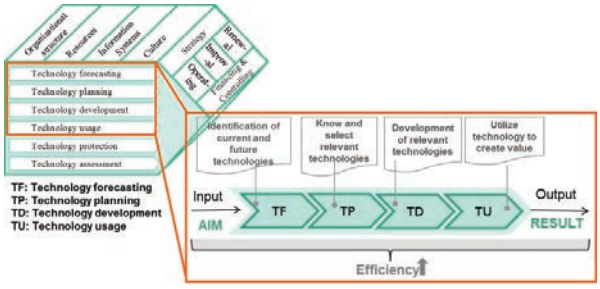

Fig. 3. Focused technology management activities.

But common controlling concepts often have the main focus on financial data and therefore lack of an adequate approach to control simultaneously technology management activities and be able to relate them to cause-effect-relationships. For this reason, a transdisciplinary approach is necessary to be able to analyze regulatory systems, their structures, constraints and possibilities of TM activities, which are often organized in a multifunctional and cross-sectional way. To handle the complexity and dynamics within TM activities requires a cybernetic perspective. It is important to understand and define the functions and processes of systems that have aims and that participate in cause-effect-linkages that move from action to sensing to comparison with the desired result – and again to action etc., with the purpose of efficiency improvement [23].

2.4. Cybernetic approach to develop a controlling-system for technology management activities

Cybernetic stands for the theory of all dynamic systems. It deals especially with information processing in dynamical systems and their regulation. Cybernetic principles have as well an association with the concept of control [24 - 28]. The cybernetics explores the essential properties of dynamical systems, so that they can process the relevant information and the systems are purposefully directed or self-steer accordingly. For the formation of cybernetic models the structure and the behavior of the selected dynamic systems (in this context: technology management in organizations) need to be researched. The structure of a dynamic system is characterized by the system limits, the subsystems and the elements of the subsystems. The relationships between the structural elements, i.e., between the system and its environment, between the subsystems and between all individual system elements that are produced by the information and are converted in the cybernetic model in cause-effect-relationships. The behavior of a system is characterized by the nature of these relationships [29], [30]. According to BEER, who applied cybernetics to activities of business management, it can be defined as *»the science of effective organization«* [31] and describes organizations as *»collections of decision elements and the channels by which they are connected«* [32]. Therefor cybernetics explores the basic concepts for the control and regulation of systems, regardless of their origin. The dominant question of cybernetics is the question of dealing with complexity and dynamics of systems.
Therefore, a model needs to be developed with a high potential to manage the technology management efficiently by diagnosing pathological and organizational conditions to design an adequate controlling system for technology management activities within the complexity of organizations.

2.5. Cybernetic understanding of controlling technology management activities.

Basing on the definition of GREEN and WELSH, wo defined cybernetic control as *»a process in which a feedback loop is represented by using standards of performance, measuring system performance, comparing that performance to standards, feeding back information about unwanted*

variances in the systems and modifying the system´s comportment« [33]. Following abstract cybernetic model (see Fig. 4), regarding to a technological system for measurement and control, is used to link technology management activities with the aspects out of figure 3 to ensure the actionability of individuals and organizations under varying objectives, turbulent environment conditions and in principle incomplete information by different planning horizons [34].

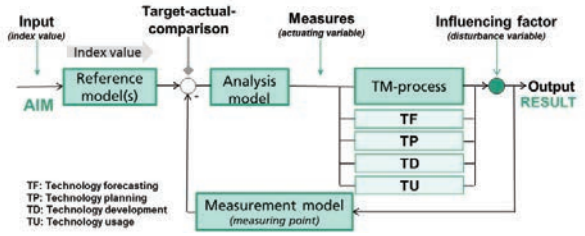

Fig. 4. Cybernetic understanding of controlling technology management activities.

Following need for research have been arisen to design a technology management controlling system:

- Which models need to be development to design a controlling-system for technology management activities? Is there one reference model or do exist more reference models, e.g. is for each technology-management-process-step (TF, TP, TD, TU) a separate reference model necessary?
- Is the defined input the right one/ are the right aims have been set?
- Which are the critical and key parameters or rather influencing factors?
- To what extent the activities contribute to the achievement of the objectives?
- Which valuation method/logic can be applied respectively need to be developed?

3. Outlook and Research opportunities

The cybernetic approach, related with the mentioned regulatory systems, its structures, constraints and possibilities of TM activities, which are often enclosed in a cross-sectional and multifunctional way, will be further developed and refined within an industrial consortium of six partners.
Along with this consortium, a survey was designed to firstly find out what tasks and methods are commonly applied in the technology management regarding to certain types of organizations and secondly, which actions are carried out in practice to control technology management. The survey draws on correlations between key performance indicators, general firm data and exercised technology management activities. These correlations can then be used to infer cause-effect-relationships. Based on these results best-practice-examples will be identified and transformed into the abstract control cycle (see figure 4). The gathered information will serve to design a holistic cybernetic approach for controlling technology management activities. A complete evaluation of the survey will be available at September 2015. Furthermore a valuation-logic for quantitative and qualitative key-performance-indicators will be developed to describe the level of aim achievement, which also serves as a component for the development of a controlling-system.

4. Conclusion

Due to the growing importance and complexity of e.g. technological developments and the relevance for organizations to persist successfully in the global competition a structured technology management process is essential for a company´s existence. This paper has investigated main challenges and difficulties of evaluating and measuring activities within the technology management process. Given the complex and dynamic cause-effect behavior of technology management activities – a cybernetic approach is necessary to design a controlling-system.

Additionally, further investigation and discussion are needed in order to clarify the arisen questions. First, it has to be analyzed which aspects influencing the performance of technology management activities in consideration with the interdependencies between the different technology management activities. Furthermore it is important to design a controlling-system to plan, manage, evaluate and control the particular technology management activities in a dynamical and adaptable way.
Within this on-going research, further work is required to detail and answer the mentioned questions, with the aim to stimulate and optimize the concept of the cybernetic framework and to develop a generic model how to control technology management activities – because control systems do not operate in isolation and technology management practices are connected with each other and the context in which they operate. In the whole cause-effect-relationships hardly comprehensible and from there conclusions are fragmentary.

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